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Identification of trend in long term precipitation and reference evapotranspiration over Narmada river basin (India)

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ABSTRACT

Precipitation and reference evapotranspiration are key parameters in hydro-meteorological studies and used for agricultural planning, irrigation system design and management. Precipitation and evaporative demand are expected to be alter under climate change and affect the sustainable development. In this article, spatial variability and temporal trend of precipitation and reference evapotranspiration (ET_o) were investigated over Narmada river basin (India), a humid tropical climatic region. In the present study, 12 and 28 observatory stations were selected for precipitation and $ET_{o,}$ respectively of 102-years period (1901–2002). A rigorous analysis for trend detection was carried out using non parametric tests such as Mann-Kendall (MK) and Spearman Rho (SR). Sen's slope estimator was used to analyze the rate of change in long term series. Moreover, all the stations of basin exhibit positive trend for annual ET_o, while 8% stations indicate significant negative trend for mean annual precipitation, respectively. Change points of annual precipitation were identified around the year 1962 applying Buishand's and Pettit's test. Annual mean precipitation reduced by 9% in upper part while increased maximum by 5% in lower part of the basin due temporal changes. Although annual mean ET_o increase by 4–12% in most of the region. Moreover, results of the study are very helpful in planning and development of agricultural water resources.

1. Introduction

Precipitation and evapotranspiration are important components of hydrological cycle and contribute vital role in agriculture water availability and planning of irrigation system development and management (Khare et al., 2006; Himanshu et al., 2017a, 2017b; Pandey et al., 2016). In recent years, many researchers were concerned about the temporal and spatial variability of precipitation rate cause of attention given to global warming (Arnell, 1999; Camici et al., 2014; Fennessy et al., 1994; Ficklin et al., 2009; Fischer et al., 2007; Holman, 2005; Liu et al., 2015; Pachauri et al., 2014; Sneyers, 1997; Ting and Wang, 1997). Trend analysis of rainfall and evapotranspiration was carried out by scientist community from different countries using different methods (Adarsh and Janga Reddy, 2015; Bandyopadhyay et al., 2009; Bawden et al., 2014; Himanshu et al., 2017a, 2017b; Jain et al., 2013; Jiang et al., 2002; Mishra et al., 2009; Partal and Kahya, 2006; Pingale et al., 2014; Shifteh Some'e et al., 2012; Widmann and Schär, 1997). Pandey et al. (2017) examined the trend of annual, seasonal and monthly precipitation applying discrete wavelet transform (DWT) and Mann Kendall test over seven Indian regions. Results indicate the both, positive and negative trend for the different region. Adarsh and Janga Reddy (2015) investigated the rainfall trend for southern India using non-parametric methods and wavelet transforms. Sequential Mann-Kendall test was applied to analyze the sequential changes in annual and seasonal trend. Kumar et al. (2016) investigated the trend of annual and seasonal precipitation and temperature over Jharkhand (India) applying non parametric tests. Results imply no significant trend in monsoon and summer session for maximum and minimum temperature while significant decreasing trend of 2.04 mm/year observed during the monsoon season for precipitation. Suryavanshi et al. (2014) examined the trend in temperature and potential evapotranspiration over Betwa basin, India. Sonali and Kumar (2013) analyzed trend of maximum and minimum temperature of annual, monthly, winter, pre-monsoon, monsoon and post-monsoon. The studies were carried out for three time slots 1901–2003, 1948–2003 and 1970–2003, for India as a whole and seven homogeneous regions of India. Authors consider the effect of serial correlation, trend detection analysis while applying MK test, Sen's slope estimator and other non-parametric methods. Mishra et al. (2009) analyzed the impact of climate change on precipitation of Kansabati basin, India. Trend and persistence of projected precipitation for annual, monsoon and pre-monsoon periods were investigated. Results implied that there will be likely an increasing trend based on A2

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scenario and decreasing trend based on B2 scenario for both annual and monsoon periods during 2051–2100. Rahmani et al. (2015) analyzed the daily precipitation of Kansas (USA) applying statistical methods and detected significant change points which were useful to manage the water resources system. Moreover, trends and persistence of precipitation data were carried out over the three major river basins Ganges, Brahmaputra and Meghna (GBM) of the Himalayan region, India by Mirza et al. (1998). Therefore basins were examined for trends applying variety of trend test namely Mann-Kendall rank statistic, Student's *t*-test and regression analysis, whereas first order autocorrelation was applied for persistence. Xu et al. (2010) carried out the study for trend detection on precipitation and runoff for Naoli River watershed, northeast China. Precipitation and discharge data from 160 meteorological stations were considered in the study. Results suggest, during 1951 to 2000 precipitation was increased in the south region and decreased in north region. Most of the trend detection study were based on parametric and non-parametric test such as Mann-Kendall (MK test) and regression analysis (Gocic and Trajkovic, 2013; Sethi et al., 2015; Shadmani et al., 2012). Tabari and Marofi (2011) analyzed the trend in ETo for 20 meteorological stations of West Iran using Mann Kendall and regression method. Analysis has been carried on the basis of monthly, seasonal and annually for about 40 years. In the results, it has been found that 70% station showing the positive trend using Mann-Kendall whereas 75% stations showing the positive trend using the regression method. Bandyopadhyay et al. (2009) has been carried the trend analysis of ET_o using Mann-Kendall for India. Authors selected 133 stations from the different agro-ecological regions from India and study carried out for the duration of 32 years. In the results, ET_o is rising for the whole India during the selected 32 years of the study period. Authors indicated the main cause of this raising trend is increase in relative humidity and decrease in wind speed for the study duration. Shadmani et al. (2012) investigated the temporal trend of arid region of Iran using Mann-Kendall and Spearman's Rho Tests. For the purpose of the study, 13 meteorological stations selected for the ET_o and the analysis have been carried out for the 41 year period. Trend detected on the basis of monthly, seasonal and annually for the duration. In the result, rising (positive) as well as decreasing (negative) trend have been found for some region but in the most of the region no trend found under the verified significance level. Tebakari et al. (2005) analyzed the pan evaporation for Kingdom of Thailand. The analysis has been carried for the 19 years (1982–2000) for considering 27 observation stations. In the result, decreasing trend were obtained for 19 station and 8 stations found as increasing trend and no station found as no- rise, no-fall trend within significant level.

In this paper, the following objectives were carried out over 12 precipitation and 28 reference evapotranspiration (ET_o) stations of Narmada river basin: (a) computation of the primary statistical parameters (mean, standard deviation, coefficient of variation, skewness, kurtosis) of the mean monthly series of 102 year (1901–2002), (b) trend detection of annual and seasonal series applying variety of methods namely Mann-Kendall test, Spearman test and Sen's slope (c) spatial distribution of temporal changes in the mean values (d) change points (shifting) detection.

2. Study area and data collection

Narmada River is one of the most important and holy river of Central India, flows from east to west direction (Fig. 1). It starts from Amarkantak Plateau (Madhya Pradesh) at an elevation of 1057 m above mean sea level, and at coordinate's latitude 22° 40′ N and a longitude of 81° 45′ E. The total length of river is about 1300 km. It passes Madhya Pradesh (1100 km), Maharashtra (35 km) and Gujarat (160 km) before it flows into Arabian Sea. The area of basin about 1,00,000 sq. km and lies between longitudes 72° 32′ E to 81° 45′ E and latitudes 21° 20′ N to 23° 45′ N. On the basis of physiography, the basin can be divided into hilly and plain regions. The hilly regions are in the upper eastern part of the basin, whereas the lower middle area is forested. The upper part of the basin is bounded by the Vindhyas, Maikala and Satpura hill on the north, east and south, respectively. The plain regions in between the hilly tracts and in the lower reaches are broad and fertile areas well suited for cultivation. Geology of basin comprises rocks ranging in age from Proterozoic to Recent. However, geology of lower part of the basin is different from the upper part and it was total absence of Palaeozoic and a major part of the Mesozoic rocks. Surface exposures of Mesozoic rocks, Deccan basalts and Tertiary sediments occur extensively in the lower Narmada basin. The region is agriculture dependent where most of the farmers sowing crops such as rice, wheat, jower, soybean and sugarcane. Climatology of the region is sub-tropical with hot and dry summer (from March to June) and cool winter (from November to February). In summer, temperature rises up to 42 °C or even more while winter temperature varies between 8 °C to 20 °C Monsoon season is very important for agriculture because of maximum rainfall. The heavy rainfall occurs in the upper hilly area and receives nearly 94% of the annual rainfall in month of June to October. The annual rainfall in the upper part of the basin is > 1400 mm and in some pockets it exceeds 1650 mm (Thomas et al., 2015). Due to change in elevation and landscape of the region, spatially and temporal variability were found in temperature and rainfall. The land use/land cover of the basin indicated different classes (Pandey and Khare, 2017). In general, higher elevated areas occupied with mixed forest, and other part of the region covered by cropland and settlement.

Monthly precipitation and reference evapotranspiration data of 102 years length (1901–2002) were used in this study, and series downloaded from India water portal website (http://www.indiawaterportal.org/metdata) maintained by Indian Meteorological Department (IMD). Seasonal and annual analysis was done for 12 stations of precipitation and 28 stations of reference evapotranspiration (Fig. 1). In general, spring or pre-monsoon season starts from March to May, monsoon season from June to August, autumn or post monsoon in September to November, and winter from December to February.

3. Tests and methodology

3.1. Trend analysis

3.1.1. Mann-Kendall test

Mann-Kendall is the nonparametric test for trend analysis. It is hypothesis testing to check the existence of trend in the terms of yes or no (Kundu et al., 2015; Kundu et al., 2014; Meena et al., 2015). It is simple and strong method, in addition to this, it can also handle the missing values and outliers (Yue et al., 2002).

The Kendall's test statistics is given as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(P_j - P_i) \tag{1}$$

$$\mathrm{sgn}(P_j - P_i) = \begin{cases} +1 & if \quad (P_j - P_i) > 0 \\ 0 & if \quad (P_j - P_i) = 0 \\ -1 & if \quad (P_j - P_i) < 0 \end{cases} \tag{2}$$

for a time series, P_i, i = *1,2,3…………,n*.

$$(\sigma_s)^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5) \right] \tag{3}$$

$$Z_{MK} = \begin{cases} \frac{(S-1)}{\sigma_s} & if \quad S > 0 \\ 0, & if \quad S = 0 \\ \frac{(S+1)}{\sigma_s} & if \quad S < 0 \end{cases} \tag{4}$$

when $n \geq 10$, S becomes normally distributed with zero mean and variance denoted as σ_s^2. t is the extent of (number of P involved) of any

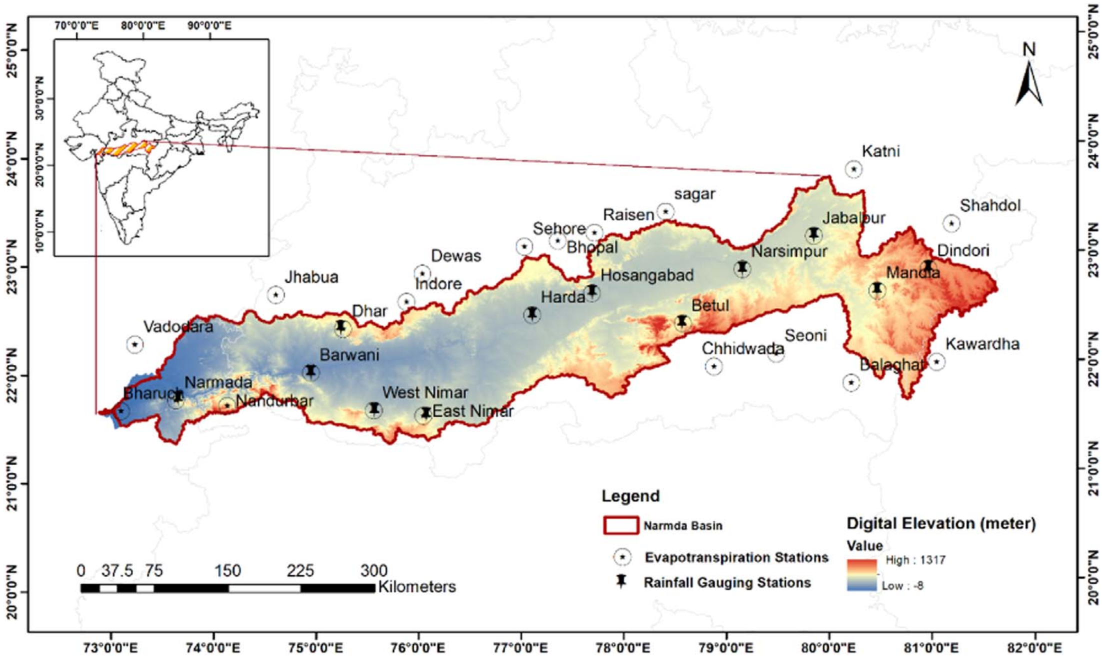

Fig. 1. Location map gauging stations in Narmada river basin.

Table 1
Primary statistical parameters values of annual and monsoon precipitation (mm) series.

SN	Stations	Annual					Monsoon				
		Mean	SD	C_V	C_S	C_K	Mean	SD	C_V	C_S	C_K
1	Barwani	848.88	15.88	22.45	0.08	− 0.05	634.95	58.74	27.75	0.31	0.86
2	Betul	974.4	17.54	21.6	0.26	− 0.07	717.24	61.64	25.78	0.25	− 0.26
3	Dhar	769.44	15.58	24.31	0.43	0.74	594.87	58.52	29.51	0.62	1.52
4	Dindori	1328.4	16.62	15.01	0.36	0.47	999.45	57.22	17.17	0.2	− 0.35
5	East Nimar	803.4	13.67	20.42	0.2	− 0.01	569.97	49.32	25.96	0.25	0.38
6	Harda	946.56	16.98	21.53	0.32	0.01	716.7	62.46	26.15	0.39	0.1
7	Hoshangabad	1136.52	20.8	21.96	0.45	− 0.16	905.34	77.36	25.64	0.56	− 0.05
8	Jabalpur	1239.36	18.09	17.52	0.41	0.03	927.45	64.77	20.95	0.36	0.11
9	Mandla	1417.32	18.79	15.91	0.51	0.56	1063.32	66.68	18.81	0.44	0.07
10	Narmada	1462.56	35.25	28.92	0.16	− 0.42	1144.98	130.81	34.27	0.26	− 0.41
11	Narsimhapur	1183.44	19.8	20.08	0.5	− 0.29	918.48	72.16	23.57	0.51	− 0.26
12	West Nimar	694.44	12.65	21.86	0.29	0.27	497.22	45.93	27.72	0.56	1.46

Note: Standard deviation (SD); Coefficient of Variation (C_V); Skewness (C_S); Kurtosis (C_K).

given tie. If $|Z| > Z_{1-\alpha/2}$, there is no trend rejected, according to the null hypothesis. Z is the standard normal variate and α is the significance level for the test (Emori and Brown, 2005).

3.1.2. Spearman Rho correlation method

It is a nonparametric test used to check the long term trend.

$$\text{Coefficient of trend } (r_s) = 1 - \frac{6\sum_{t=1}^{n} d_t^2}{n(n^2-1)} \quad (5)$$

where, $d_t = R_{xt} - t$, and R_{xt} is the rank of the series x_i,

$$ts = rs\sqrt{\frac{n-2}{1-r_s^2}} \quad (6)$$

For two tailed test, denote the critical value as $(\pm\, ts_{\frac{\alpha}{2},n-2})$, if $s > ts_{\frac{\alpha}{2},n-2}$ or $ts < ts_{\frac{\alpha}{2},n-2}$, null hypothesis can be rejected (Shadmani et al., 2012; Yue et al., 2002).

3.1.3. Sen's slope estimation test

Sen's slope is the tool to estimate the monotone trend of the equally spaced time series data. In this study, it is used to quantify the slope of the series.

$$\beta = \text{Median}\left(\frac{P_i - P_j}{i - j}\right) \text{ for all i < j} \quad (7)$$

where, β is the slope between data points P_i and P_j (Sethi et al., 2015).

3.2. Spatial variability (percentage change in mean)

In order to compute the annual and seasonal spatial variability in hydro-climatic parameters, magnitude of Sen's slope of natural log series were used. By using Eq. (8), percent change in mean value of climatic parameters can be estimated:

$$\Delta P = (e^{\beta} - 1) \times 100t \quad (8)$$

where, ΔP = percent change of climatic parameter over period, β = Sen's trend slope (natural logarithmic series), and t = total length of trend period (years). However, spatial variability of parameter may carried out by spatial interpolation methodology.

Table 2
Primary statistical parameters values of annual ET_o (mm/day) series.

SN	Station	Elevation (m)	Mean	SD	Cv	Cs	Ck
1	Balaghat	288	4.97	0.06	1.17	0.94	2.63
2	Barwani	178	5.22	0.05	0.94	0.10	− 0.63
3	Betul	658	5.00	0.05	0.92	0.09	− 0.51
4	Bharuch	15	4.75	0.04	0.81	0.42	0.19
5	Bhopal	527	4.93	0.05	1.05	0.02	− 0.36
6	Chhidwada	675	4.81	0.05	1.02	0.43	0.32
7	Dewas	535	5.14	0.05	0.99	0.13	− 0.61
8	Dhar	559	5.09	0.05	1.01	0.19	− 0.57
9	Dindori	640	4.69	0.07	1.47	1.30	4.69
10	East Nimar	309	5.24	0.05	0.89	0.16	− 0.51
11	Harda	296	5.15	0.05	0.91	0.12	− 0.63
12	Hosangabad	278	4.89	0.05	0.99	0.04	− 0.46
13	Indore	553	5.15	0.05	1.03	0.18	− 0.60
14	Jabalpur	412	4.73	0.06	1.18	0.76	2.45
15	Jhabua	318	5.05	0.05	0.97	0.18	− 0.56
16	Katni	304	4.80	0.06	1.23	0.66	2.48
17	Kawardha	353	4.81	0.07	1.37	1.25	4.12
18	Mandla	445	4.82	0.06	1.28	1.10	3.77
19	Nandurbar	210	5.02	0.05	0.90	0.15	− 0.54
20	Narmada	140	4.96	0.04	0.86	0.23	− 0.26
21	Narsimpur	347	4.62	0.05	1.14	0.58	1.55
22	Raisen	321	4.88	0.05	1.09	− 0.03	0.18
23	Sagar	427	4.78	0.06	1.15	0.14	0.39
24	Sehore	502	5.05	0.05	1.01	0.09	− 0.63
25	Seoni	611	4.82	0.05	1.11	0.72	1.84
26	Shahdol	464	4.61	0.07	1.52	1.33	5.03
27	Vadodara	129	5.03	0.04	0.88	0.39	− 0.02
28	West Nimar	241	5.26	0.05	0.95	0.11	− 0.58

Note: Standard deviation (SD); Coefficient of Variation (%) (C_V); Skewness (C_S); Kurtosis (C_K).

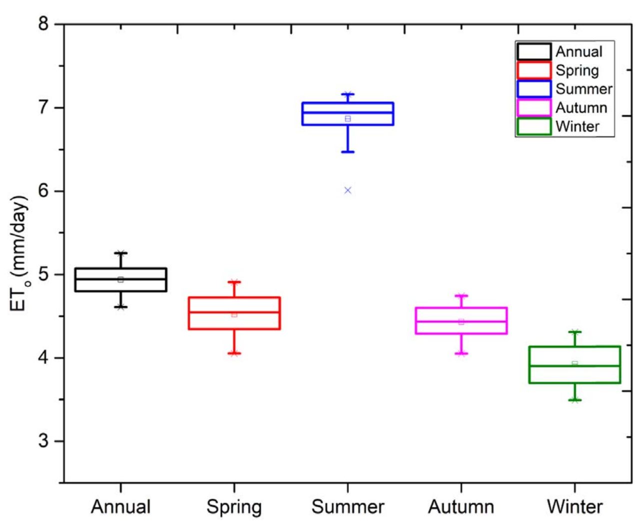

Fig. 2. Annual and seasonal variability of reference evapotranspiration (mm/day) over Narmada basin.

3.3. Change point (shifting)

There are two tests used to detect the change point of rainfall data using Buishand Range test (BR test), and Pettitt test. Both tests have capability to detect the change year (shifting) in the time series (Alexandersson and Moberg, 1997; Buishand, 1982). BR test and Pettitt test can easily identify the change point in the middle of the series. Besides, BR test assumed series is normally distributed, whereas Pettitt test does not need this assumption because it is a non-parametric rank test (Pingale et al., 2014; Sethi et al., 2015).

3.3.1. Buishand range test

This method is also known as Cumulative Deviation Test, which is based on the adjusted partial sums or cumulative deviation from the mean.

$$S_o^* = 0 \text{ and } S_k^* = \sum_{i=1}^{k} (P_i - P_{mean}),$$

$$k = 1, 2.........,n \tag{9}$$

$$S_k^{**} = S_k^*/\sigma \tag{10}$$

$$R = Max|S_k^{**}| - Min|S_k^{**}|, 0 \le k \le n \tag{11}$$

The $R/\sqrt{n}$ is then compared with the critical values given by (Buishand, 1982; Peterson et al., 1998).

3.3.2. Pettitt test

This test is basically based on the rank of the series and ignores the normality of the series

$$Q = Max\ |X_k|$$
$$1 \le k \le n \tag{12}$$

$$X_k = \sum_{i=1}^{k} r_i - k(n+1)$$
$$\text{where,} i = 1, 2, ...n \tag{13}$$

The change years in the *Kth* year of the max X_k value (Bawden et al., 2014; Costa et al., 2008).

4. Results and discussions

4.1. Statistical parameters of precipitation and reference evapotranspiration

The primary statistical parameters of precipitation series (1901–2002) such as mean, standard deviation, skewness, kurtosis and coefficient of variation were computed for annual and monsoon season (Table 1). Table 1 indicates the minimum average annual precipitation received at West Nimar (694 mm) a south-east station and maximum for Narmada (1462 mm), one of the west station of the basin. Although monsoon precipitation is contributing about 60% to 80% of the total annual precipitation. The standard deviation varied between 12.65 and 35.25 mm for West Nimar and Narmada respectively. The skewness (Cs) parameter represents the measure of asymmetry in a frequency distribution around the center point. Moreover, kurtosis parameter indicates the measurement of outliers, relative to normal distribution. High kurtosis value exhibits the high tailed (outlier) and low kurtosis value indicates flat tailed (lack of outlier). Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak, it varies from − 0.01 to 0.74 and − 0.05 to 1.52 for average annual and monsoon rainfall respectively. The coefficient of variation (C_V) represents the ratio of standard deviation to mean of the data series. The coefficient of variation varies between about 15% (Dindori) to 25% (Dhar) station and about 17% (Dindori) to 29.51% (Dhar) for annual and monsoon season respectively (Table 1).

Reference evapotranspiration (ET_o) is an important agrometeorological parameter for climatological and hydrological studies. It is also one of the most significant factor for planning, management and scheduling the irrigation system. Table 2 and Fig. 2 indicate the primary statistical parameters of annual and seasonal reference evapotranspiration (ET_o) from 28 stations of Narmada river basin. Mean annual ET_o lies between 4.61 (Shahdol) to 5.26 mm/day (West Nimar). Mean maximum and minimum seasonal values of ET_o value of 102 years were observed for winter season 4.31 mm/day (Narmada) and 3.49 mm/day (Shahdol), for spring 4.91 mm/day (Barwani) and 4.05 mm/day (Shahdol), respectively.

4.2. Trend in annual and seasonal precipitation

Trend detection of precipitation series was carried out using Mann

Table 3
Results of Mann Kendall (MK) test, Spearman Rank (SR) and Sen's slope (SS) (mm/year) based on annual and seasonal precipitation series.

Stations	Annual			Monsoon			Non-Monsoon		
	MK	SR	SS	MK	SR	SS	MK	SR	SS
Barwani	1.04	1.06	0.060	0.65	0.68	0.131	1.41	1.35	0.051
Betul	− 0.91	− 0.95	− 0.062	− 0.78	− 0.82	− 0.185	− 0.47	− 0.52	− 0.017
Dhar	0.53	0.55	0.034	0.17	0.22	0.029	1.41	1.39	0.045
Dindori	**− 1.88**[b]	**− 1.98**[a]	− 0.103	− 1.6	**− 1.65**[b]	− 0.314	− 0.68	− 0.68	− 0.025
East Nimar	− 0.49	− 0.43	− 0.025	− 0.46	− 0.41	− 0.091	0.21	0.18	0.009
Harda	− 0.90	− 0.92	− 0.061	− 0.97	− 0.92	− 0.203	− 0.31	− 0.34	− 0.008
Hoshangabad	− 0.49	− 0.87	− 0.025	− 0.46	− 1.08	− 0.091	0.12	0.08	0.003
Jabalpur	− 0.76	− 0.91	− 0.043	− 1.14	− 1.22	− 0.251	0.35	0.29	0.014
Mandla	− 1.46	− 1.56	− 0.086	− 1.42	− 1.48	− 0.327	− 0.34	− 0.43	− 0.016
Narmada	− 0.39	− 0.31	− 0.052	− 0.56	− 0.49	− 0.257	1.41	1.33	0.102
Narsimhapur	− 0.55	− 0.63	− 0.037	− 0.94	− 0.92	− 0.223	0.29	0.25	0.013
West Nimar	0.77	0.80	0.033	0.35	0.38	0.049	1.08	1.01	0.032

Note: [a] and [b] bold values show the 5% and 10% of the significant level of trend, where positive and negative values show the increasing and decreasing trend respectively.

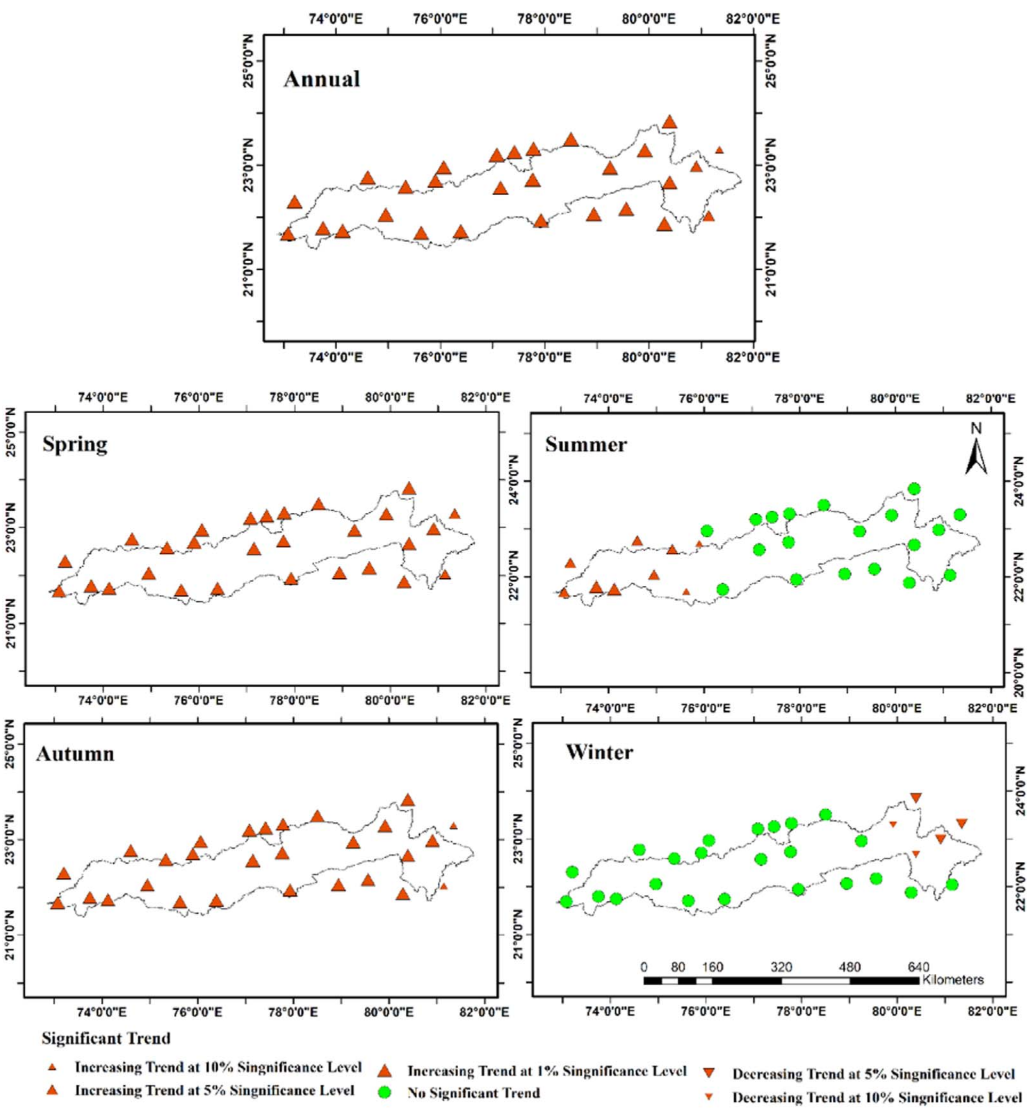

Fig. 3. Annual and seasonal variations of Mann- Kendall Z value of ET_o showing trend at different stations.

Kendall (MK) test, and Spearman Rank (SR) test based on the null hypothesis of 5% and 10% significance level (Table 3). Before applying the trend test, precipitation data was tested for serial correlation to eliminate the effect of serial correlation. In general, most of the stations indicate 'no trend' in the precipitation series for annual, monsoon and non-monsoon series. Dindori station exhibits significant decreasing trend at annual period for MK and SR test whereas monsoon season experience significant negative trend based on SR test. The rate of change (mm/year) evaluated by applying the Sen's slope method. The maximum rate of change in mean values of precipitation was − 0.103 mm/year by Sen's slope for Dindori station. Rainfall station Narmada was showing the significant trend at the 10% significance

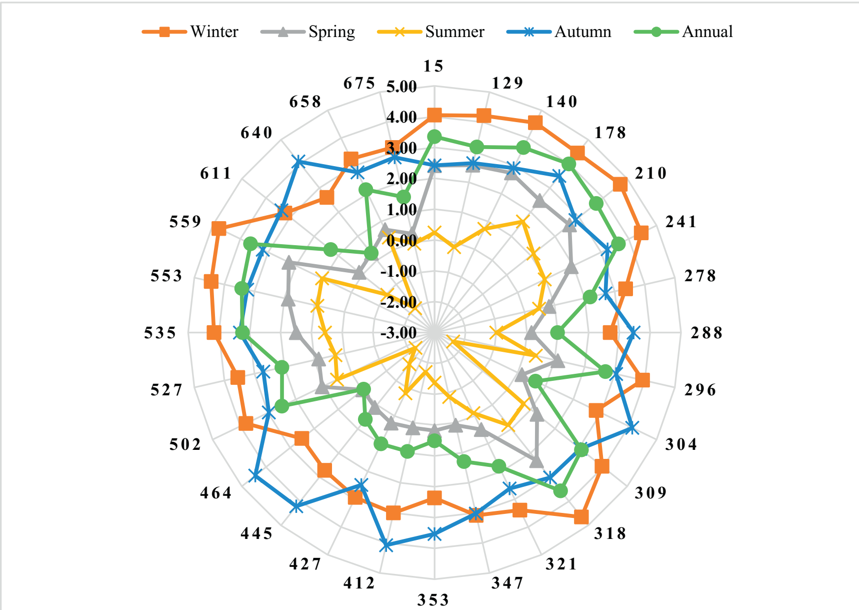

Fig. 4. Variation of MK Z value and elevation of stations.

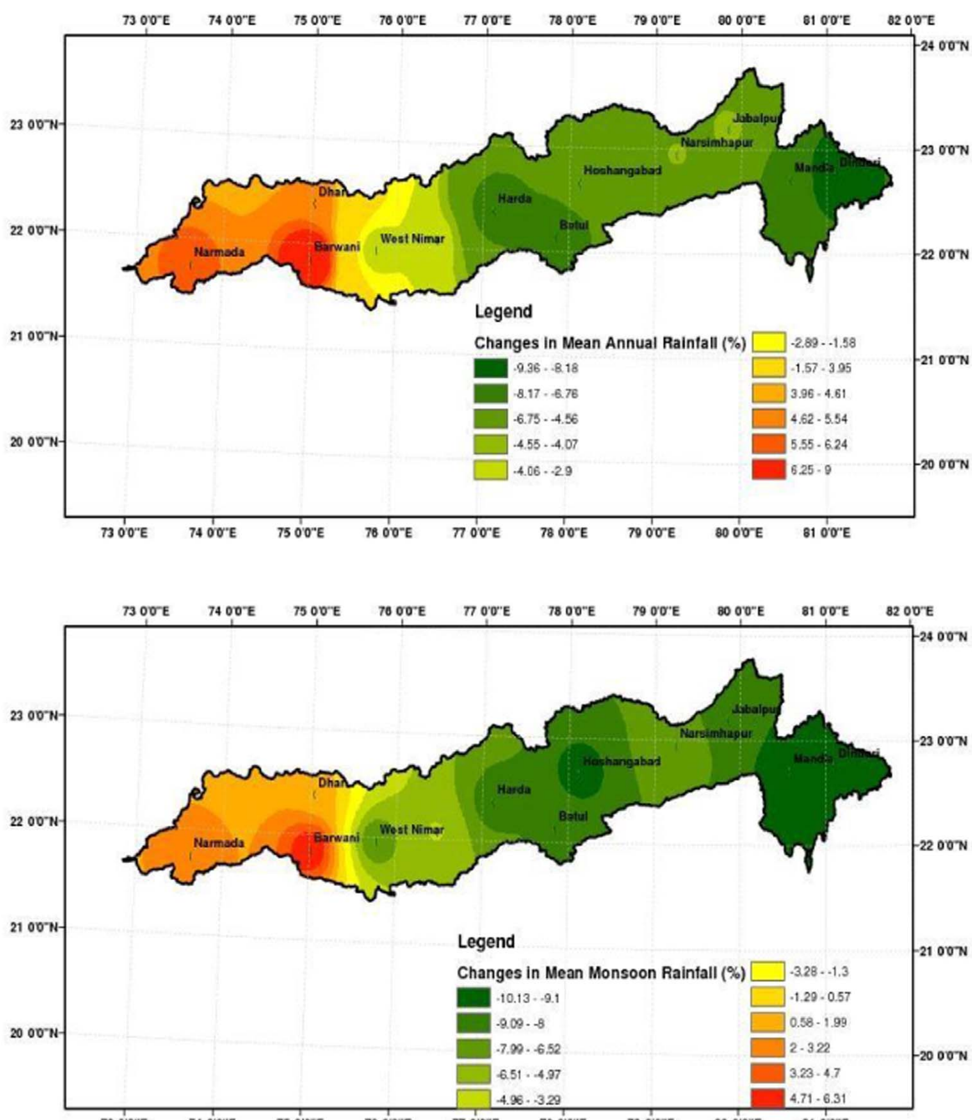

Fig. 5. Spatial distribution of temporal changes in rainfall (changes in percentage) from mean value for annual and monsoon period.

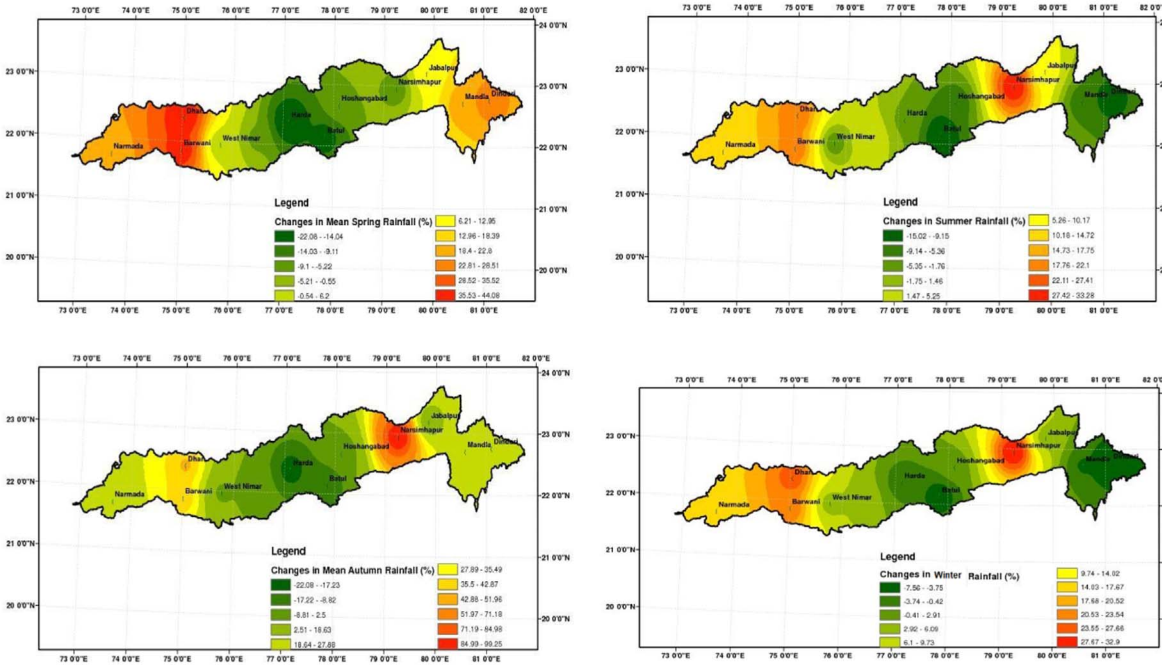

Fig. 6. Spatial distribution of temporal changes in rainfall (changes in percentage) from mean value for seasonal period.

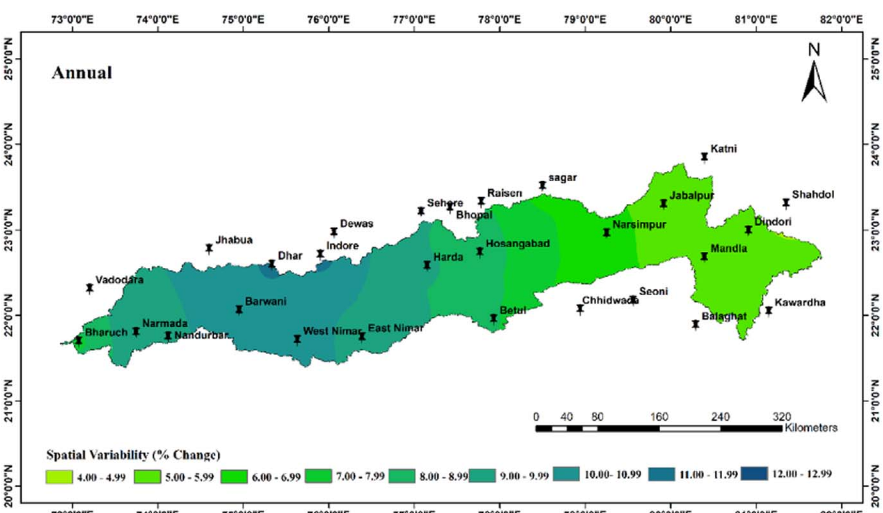

Fig. 7. Spatial distribution of temporal changes in reference evapotranspiration (changes in percentage) from mean value for annual.

level for autumn season. Except rainfall stations Barwani, Dhar and West Nimar, most of the stations indicated a negative rate of change in the rainfall over the period. Barwani, Dhar and West Nimar indicated the positive slope for annual and monsoon season. There is no trend experienced during non-monsoon season in the region.

In order to compare the MK and SR test, outcomes obtained using both tests show that the significant values of MK and SR tests with reference to total numbers for detections of trend in ET_o were 4% and 8%, respectively. Therefore, these tests had almost similar performance at the 5% significant level for analysis of trends. In cases where the detection of significance by means of the two tests was different, values of significant level of trend acceptance exhibited low difference. Shadmani et al. (2012) also confirmed similar performance of MK and SR tests for analysis of trends.

4.3. Trend in annual and seasonal reference evapotranspiration

Long term trend of ET_o detected for annual and seasonal period based on 5% significance level. Monthly analysis indicates no trend in the month of January, May, June and August in the basin. In upper part of the basin, no significant trend was found in month of March and April. Although significant positive trend was noticed in month of February, October, November and December. In lower Narmada river basin, positive trends were found in the month of March and April. In Fig. 3, indicate 'no trend' 'positive trend' and 'negative trend' over the Narmada basin. Seasonal study indicates that positive significate change in the autumn and winter in the river basin. There were no significant trends in Narmada for spring and summer (excluding stations Dindori, Shahdol and Katni). Negative trend were noticed in the summer for stations Dindori, Shahdol and Katni. Annual base study indicates that positive trend in the most part of Narmada at the 5% significance level. Upper Narmada stations Mandla, Dindori, Katni and Kawardha indicated the positive trend at 10% significance level. Only station of Upper Narmada, Shahdol indicate that no trend in 5% significance level during the 102 years. Moreover spatial distribution of ET_o trends showed that annual and autumn trends were entirely significant positive at all the stations, while west stations situated at lower elevation exhibit positive trend of Narmada basin.

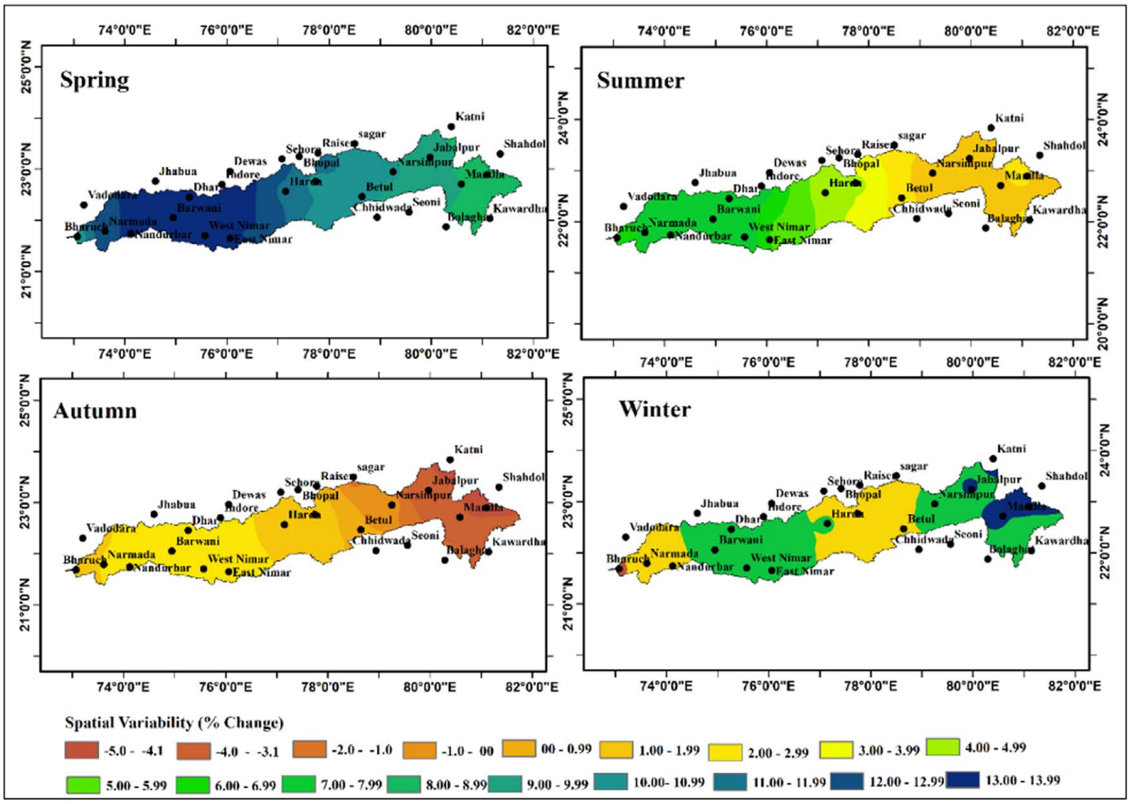

Fig. 8. Spatial distribution of temporal changes in reference evapotranspiration (changes in percentage) from mean value for season.

Increasing ET_o trends were observed in the spring and autumn seasons over the 100% of the stations. Negative ET_o significant trends at the 95% confidence levels were observed in winter seasons, for 14% of the stations while rest of the stations exhibit 'no' significant trend in the region. Therefore, stronger increasing trends were identified in ET_o data in autumn and winter compared with those in summer and spring. In general, at the temporal scale, most of the stations showed increasing trend at annual period. An increasing trend in annual and seasonal ET_o mostly took place at stations in the middle and lower part of the basin (Fig. 4).

4.4. Spatial distribution of temporal changes in annual and seasonal precipitation

Spatial variability over the region were evaluated and drawn by using a geospatial tool (ArcGIS10.2). By using ArcGIS10.2 tool, contour map of spatial rainfall variability were generated using an Inverse-Distance-Weighted (IDW) algorithm (Shifteh Some'e et al., 2012). To predict a value for any unknown location, IDW employs the known values surrounding the prediction location. Narmada basin occupied by agriculture area and forestry. Upper part of Narmada is mountainous and covered by forest. The rainfall variation influenced by the eco-system and changes in landscape. Deforestation in the upper part of Narmada river basin is one of the reason of changes in rainfall distribution, in addition to climate change (Mondal et al., 2015). Figs. 5–6 indicate the annual and seasonal spatial variability of mean precipitation. Fig. 5 indicate the changes in mean value of rainfall for annual and monsoon period. Changes in mean values varies from -9.36% to $+9.00\%$ at annual scale and -10.13% to $+6.31\%$ at monsoon period. Upper eastern part of the basin for annual and monsoon season exhibit decreasing mean values. In the lower part of the basin, rainfall were increasing for annual, monsoon and spring.

4.5. Spatial distribution of temporal changes in annual and seasonal evapotranspiration

Figs. 7–8 show spatial distribution of temporal changes in ET_o for annual and seasonal period. Temporal changes in ET_o series evaluated based on Sen's slope estimator using Eq. (8). Upper part of the basin indicate lower changes as compared to mid and lower part of the basin in the mean annual ET_o. Moreover stations exhibit low changes in mean ET_o are situated at high elevation. Overall changes in annual mean ET_o were found about 7% over the basin. Stations (Narmada, West Nimar, Indore, Dhar) from lower part of the basin indicate maximum changes in mean values and lies between 8 and 12%. Seasonal maximum changes were noticed for middle part of the basin for spring season. Stations from upper part of the basin exhibit negative changes in autumn.

4.6. Relationship of ET_o with hydro-meteorological parameters

Reference evapotranspiration is mainly controlled by variations in air temperature, solar radiation, relative humidity and wind speed in any region. Therefore, effect of meteorological in the ET_o series was investigated in view of the trends of the other variables such as mean temperature, maximum temperature and minimum temperature (Fig. 9). To analyze the trend effect of temperature on ET_o, basin has divided in to three different part based on physiography of the region, namely, the upper zone comprising of the hilly region covering the districts of the Shahdol, Mandla, Balaghat, Seoni, Jabalpur, Narsinghpur, Sagar, and Damoh; the middle zone, comprising of a plains region cover the districts of Chhindwara, Hoshangabad, Betul, Raisen, Sehore, and Khandwa; and the lower zone comprising of the lower hilly and lower plains region covering the districts of East and West Nimar, Dewas, Indore, Dhar, and Narmada. From each part of the basin, one representative station from upper hilly region Jabalpur, Hosangabad from middle plain region and Narmada station from lower part of the

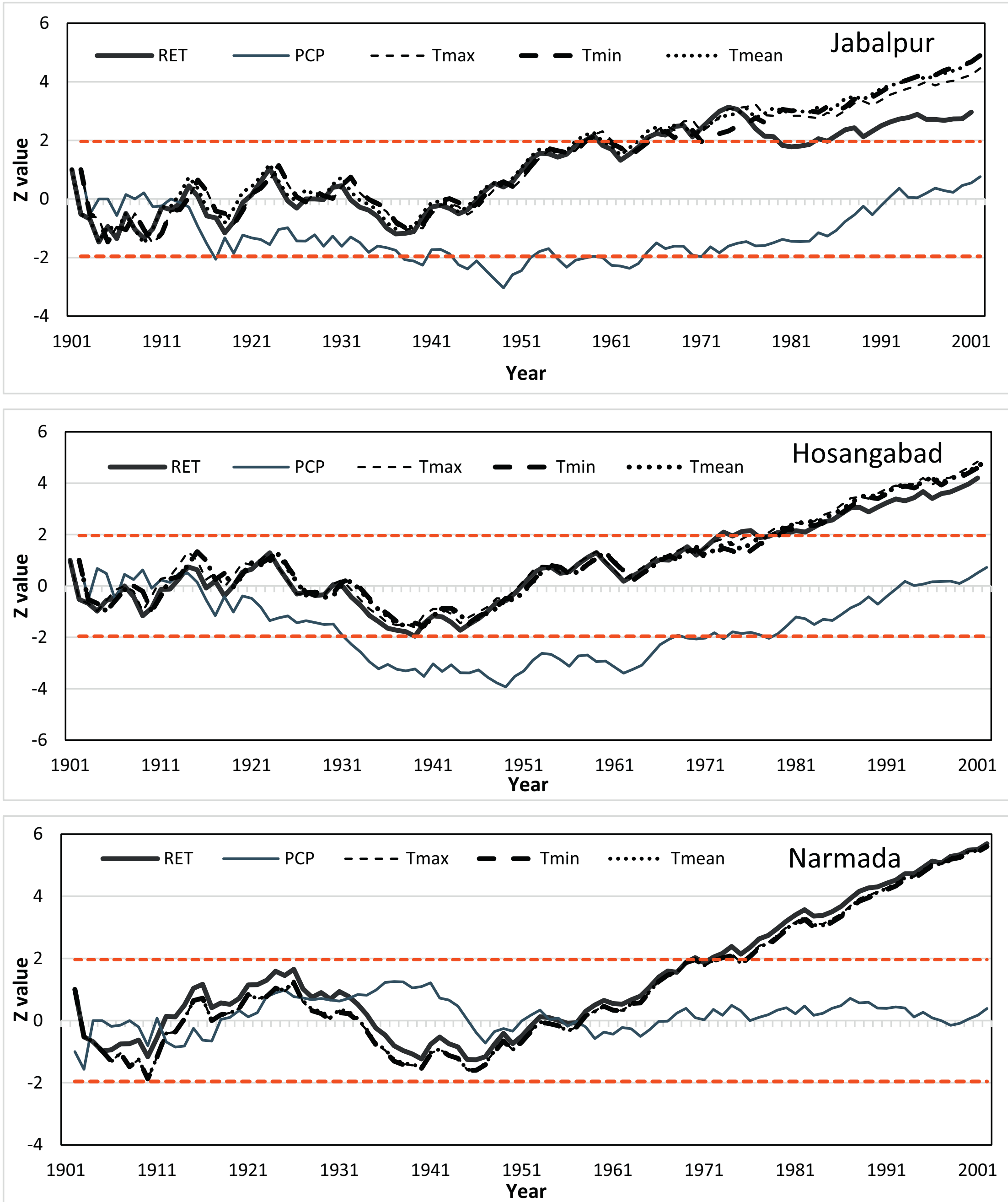

Fig. 9. Sequential MK–Z value of hydro-meterorological parameter.

basin selected for the sequential temporal trend analysis (Fig. 8). Figure indicate the significant trends applying Mann–Kendall test for the mean annual meteorological variables time series. The Mann–Kendall test was applied for detecting trends in the meteorological variable, temperature (mean, maximum and minimum). The statistical test shown significant positive trends in temperature (mean, maximum and minimum) in 100% of the stations for annual series. Meanwhile, the results showed that the precipitation annual series significantly decreased at 8% of the stations during the study period. The increasing trends in the temperature (mean, maximum and minimum) series show strong agreement with trend found in ET_o. Although it was thus expected that, similarly of trend in temperature with trend in ET_o, show an overall increasing trend during the study period. Overall, it can be derived from the study results that the increase in ET_o in the study area is mainly due to a significant increase in air temperature. A marginal increase in ET_o due to climate change would therefore put enormous pressure on the existing meager water resources.

4.7. Change year (shifting) in precipitation

The change point of each of the station of the regions is given in Table 4 indicating the point of change (shifting) in the trend during 1901 to 2002 (102 years) of precipitation applying Buisand and Pettit's. Although the break points are quite variable, 1962 was found to be the most probable break point for annual and monsoon rainfall as observed in 12 stations for the entire region. For non-monsoon period, no such specific time was observed. There was a lack of any predominant change point here. There are many reasons for change point such as due to relocations of the station, changes in instrument exposure and urban influence changes in observing schedules and practices, or abrupt

Table 4
Identification of shifting year using Buishand Range test (BRT) and Pettit's test (PT).

Stations	Annual		Monsoon		Non-monsoon	
	BRT	PT	BRT	PT	BRT	PT
Barwani	**1929**	**1929**	**1929**	**1929**	**1974**	**1974**
Betul	**1962**	**1962**	1976	1962	1949	1951
Dhar	**1929**	**1929**	**1929**	**1929**	**1974**	**1974**
Dindori	1949	1978	1973	1978	**1949**	**1949**
East Nimar	**1929**	**1929**	**1929**	**1929**	1949	1913
Harda	**1962**	**1962**	**1962**	**1962**	1948	1949
Hoshangabad	**1962**	**1962**	**1962**	**1962**	**1949**	**1949**
Jabalpur	1973	1983	1973	1983	**1908**	**1908**
Mandla	1971	1949	1973	1949	**1949**	**1949**
Narmada	1941	1964	**1964**	**1964**	**1974**	**1974**
Narsimhapur	1963	1978	1973	1978	**1908**	**1908**
West Nimar	**1929**	**1929**	**1929**	**1929**	**1974**	**1974**

Note: Bold year indicated the same shifting year for both test.

changes in the atmosphere (Alexandersson and Moberg, 1997). However results from both tests, Buisand and Pettit's test are very similar and showing almost same results.

5. Conclusion

For planning and management of agriculture and water resources, it is important to understand the distribution and changing trend of rainfall and evapotranspiration under climate change. The change in rainfall distribution mainly controlled by the ecosystem and landscape changes whereas evapotranspiration influenced by vegetation, soil cover, solar radiation, temperature and wind. However, change in precipitation rate is cause of climate change and deforestation in the upper part of river basin. Moreover trend of the annual and seasonal precipitation and reference evapotranspiration were analyzed with Mann Kendall (MK) and Spearman Rank (SR) test. Both tests indicate very close results in most of the cases. Variability and trends (magnitude) in annual and seasonal precipitation of 12 stations were computed by Sen's slope. Results indicate that less changes in mean precipitation value at higher altitude region (Upper Narmada) while significant changes found in the lower region of Narmada. Lower portion basin exhibit increasing trend with rate of magnitude 0.060–0.033 mm/year for annual precipitation, whereas upper part show the decreasing annual rainfall with the rate of 0.10–0.025 mm/year. In summer, rate of changes in mean precipitation lies within range of -0.011 to 0.233 mm/yr. The stations Dhar, East Nimar, Harda, Hosangabad, Jabalpur and Narmada were not indicate the significant trend for annual and seasonal precipitation series. Although Dindori station exhibit significant negative trend at 95% confidence level for annual and monsoon season. Change point detection by Buisand and Pettit's show same result for most of the stations and shifting year starts around 1962 for annul precipitation series. Trends of the annual ET_o series were analyzed for 28 stations indicate that significant positive trend in 100% of the stations of the study area. Therefore, temperature was the main causes of the increase in ET_o trends. In general, ET_o is an important indicator that show the irrigation water demand. Moreover results of the study are very helpful in planning and development of agricultural water resources and implementation of policy for agriculture water management.

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